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Design of a system to monitor and control solar pond: A review

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Abstract

Salinity gradient solar ponds are green energy collectors. Energy is captured by creating a temperature gradient across the depth of the pond. All energy is from the solar radiation incident at the surface. Salinity gradient, maintained and changed with the depth, contributes to the temperature differences of up to sixty degrees. The heat generated can be used directly for a wide range of purposes, or can be converted to electricity which can be used in the plant, or shipped to the grid. Number of solar pond parameters, i.e. physical quantities, important for the correct functionality of this type of energy production plants, is mainly monitored locally, at the pond sites. Remote data acquisition (DAQ), and following that, control of the solar pond energy production, is more convenient and this is the subject of our research, reported here. With the application of wireless, or wired networks, virtual private networks and Internet a solar pond control centre could be located anywhere in the world, while the pond's sites are selected at the best solar potential places.

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Keywords: Solar pond; DAQ system; Communication system; Remote Monitoring, VPN;

1. Introduction

Our research focusses on defining a system in place that could be used for the support of the solar pond based green energy systems. System can successfully record the values of the energy production plant parameters, which we are looking for, as well as use a system of communication networks by which this data flows freely from the source of acquisition to the point of monitoring and control. The pond is based on the principle of collection of energy by creating

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a temperature gradient in the pool of water. Proper gradient pattern prevents heat from incident solar radiation leaving the pond. This is done by way of increasing the level of salinity through the depth of the pool. The heat is passed from layer to layer through convection with the bottom layer maintaining the highest temperature. The atmospheric conditions at the surface of the pond play a prime importance in shaping up the conditions for the effective functioning of the pond throughout the year, namely the temperature, humidity, wind velocity being the dominating factors. The other, in-pond variables, can be altered and monitored as per the requirement of the optimal energy collection. The set of ambient conditions is not something that could be under our control. We cannot control ambient conditions, but, we still could select the best location for the solar ponds across the country. An RMIT University experimental solar pond was built in 1998 and is used by School of Engineering Conservation and Renewable Energy Group. Pyramid Hill is one of the new selected locations. A solar pond system could use a robot [1], or wireless sensor network (WSN), to collect data from different depths in the pool and it is linked to the flow control into the pond but requires a Data Acquisition system to be fully configured for remote monitoring. New communication trends, with standardisation of initiative Internet of Things (IoT), enables and enhances remote monitoring and control using computer networks' infrastructure.

Nomenclature

SGSP	Salinity Gradient Solar Pond
IoT	Internet of Things
WSN	Wireless Sensor Networks
DAQ	Data Acquisition Systems
4G	Generation 4 of Communication Infrastructure
VPN	Virtual Private Network

1.1. Solar pond principles of operation and monitoring

Experimentation solar ponds like those in Iran[2] are used mainly to assess the feasibility of a site and its potential for generating power and are hence smaller. Ponds which are implemented have already been through this either, by simulation, or by experimentation at a university/government initiatives and are deemed suitable for larger scale applications. It has also been shown that circular ponds have better energy collection efficiencies than square ponds[2]. The general functionality of the pond is described below with emphasis on how the layering is done with different percentage of salinity in the layers. The pond is mainly divided into three layers: The Upper Convective Zone (UCZ), The Non-Convective Zone (NCZ) and the Lower Convective Zone (LCZ) which is also the energy storage area. They can be schematically represented as shown in the Fig. 1.

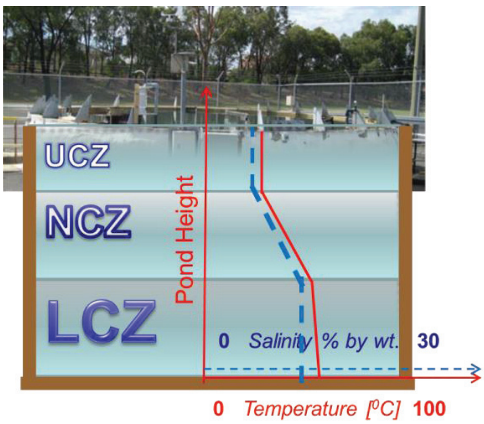

Fig. 1. Salinity and temperature distribution across depth of the pond

The UCZ is closest and directly in contact with the air above it and is hence at ambient temperature. The layer below it, which is the NCZ is what keeps the topmost layer and the bottom layer thermally separated from each other. The salt content in this layer is higher than the layer above it and it is also denser. The bottom layer which is LCZ has the highest salt content and the gradient, and following the higher temperature.

This process of gradient distribution does not occur naturally and needs to happen systematically. The system usually comprises of some sensing elements to sense physical factors such as salinity, temperature, or turbidity etc., which affect the solar energy absorption of the pond under consideration. The values generated from the sensing elements must be converted to a user friendly format to be understood and used to control the flow of water to the tank and/brine solution which is used to adjust the salinity levels in the pond or lake [3].

Table 1. Solar pond physical quantities

Physical quantity	Scan rate	Displacement	Comment
Solar Radiation	60 sec	Single point	Anywhere
Ambient temperature	60 sec	Single point	Anywhere
Wind	60 sec	Single point	Anywhere
Surface temperature	5 min	Single point	
Bottom temperature	10 min	Single point	
Temperature vector	5 min	5 cm	T(x[m],t[sec])
pH vector	24 hours	5 cm	pH(x[m],t[sec])
Density vector	24 hours	5 cm	D(x[m],t[sec])
Turbidity vector	24 hours	5 cm	Tb(x[m],t[sec])

Researchers at RMIT University have built a pond in the Bundoora campus to understand the flow of energy, perform data acquisition and control. Research findings which are generalised onto a larger scale are used to build expertise of the CARE group. The system, used by University, consists of a pond on which different various tests are carried out. For the comprehensive list of all solar pond system variables, scanning rates and RMIT pond's measurement results please refer to [4].

Updated set of physical quantities monitored is shown in the Table 1. There are nine quantities that we monitor. They are system variables, but not all of them are crucial for the solar pond system functionality. Temperature, pH, density and turbidity are vector type variables since we measure them at the distance of 5cm through the depth of the pond. If pond is 2m deep all our vectors have 40 components each. Since systems variables are defined let us now have a quick look at the communication and data storage system requirements. Single reading of any of those variables, i.e. vector components, could be easily represented by a floating-point number. As per IEEE standard for 32-bit floating point numbers, we are using 4 bytes for each sampled value. That gives us the range of numbers that could be represented as following ($10^{-38} – 10^{+38}$), with the 7 digits' precision. Since there are 5 scalar variables and 4 vector variables with 40 components, in the rare time instances when we sample all of them, we need (5+4*40)*4=660 bytes for the representation of the sampled data. For the whole day of data acquisition, with 16392 samples, with 4 bytes each, we need total of 65568 bytes, i.e. 65.568kbytes. For the whole year, of 365 days, we have 23.93232 Mbytes of data. This is easy to store and transfer locally, and centrally, using current communication and data storage facilities, as will be shown later.

2. Solar installations worldwide

Some solar ponds from different parts of the world with different environmental and climatic conditions are covered briefly to show the diversity of how the concept manifests itself in various environments. Solar pond constructed in Jordan's arid climate is a perfect fit for its location where studies show the mathematical modelling behind the plant and the efficiencies of energy storage in the different layers of the pond namely the NCZ and the LCZ. The temperatures reach high values with the ambient temperature in the surroundings reaching a peak of 40°C near the

UCZ. The main purpose of the pond is desalination which is like the one at Pyramid Hill. None of the research points to the method of monitoring of the pond or the accuracy of the measurements. The area around the Dead Sea is known for having excessive levels of salinity and solar ponds being a viable and economically feasible option for the area[5].

The pond at El Paso in Texas is probably the most famous of the solar pond installations in the world and serves as a benchmark for technology associated with Salinity Gradient Solar Pond (SGSP). The DAQ system measures properties related to the pond as temperature, turbidity, density and pH by means of a scanner which has measuring points along the depth of the pond. The data obtained is logged using a computer from a location nearby. A sixteen-year study with its focus mainly on this pond shows how temperature measurements were taken twice a day with other data logged at different frequencies to monitor the pond and ensure its smooth operation.

The other pond, in Tibet, is unique with respect to its location because it works in such low temperature that the maximum temperature is well under 50 °C but in regions where the minimum ambient temperature is negative during winter, the positive temperature difference of 29 °C shows prospective for development and desalination. A distinctive feature of this pond is that it uses a variety of salts to create the salinity gradient mainly by magnesium salts. A shortcoming of the study conducted tells us that, the duration of the study does not give conclusive results as it ran only for a period of 105 days and not through the whole year[6].

The system at El Paso is diverse because of the magnitude of the project; the sensors work much faster and can make recordings of the physical quantities in a shorter time span as compared to other systems. The level of automation in this plant is also higher, allowing for readings to be taken and analysed more quickly. The data obtained at this plant however is stored only locally and analysed at the Texas A&M University. This is good from a data security point of view but limits future research into the plant as the real time data cannot be passed onto researchers at other places who could potentially improve the results of the plant [7].

Researchers in Algeria have built experimental solar ponds within the University of Annaba to study the effects of the use of different salts in the ponds as the brine solution. The heat transfer between the pond and the surroundings has been analysed using the law of conservation of energy. The theoretical results have then been compared with the experimental results which have almost negligible level of errors. The temperature monitoring was done with the help of a thermocouple at a frequency of three hours. One of the major contributions of this study was the identification of the thermal conductivity of salts such as Sodium Carbonate and use of Calcium Chloride as a brine solution for newer sites because of its high conductivity[8].

Solar ponds have been constructed in Turkey with surface areas and almost uniform depth for two separate cases to study the effect of the amount of sunny area in a zone of a solar pond mainly the LCZ. It is expressed as a ratio of total area with solar radiation incident on the area. This study allows for modelling of solar ponds prior to construction with better accuracy as we the researchers go beyond numerical modelling [9] of the pond and it is a very important aspect to any environment. By knowing the temperature variance in an area coupled with the cloud cover for different times in the year, the study could determine a novel approach to thermal efficiencies obtained from ponds in different parts of Turkey[10].

Researchers in Cyprus have constructed a pond and used Computational Fluid dynamics to study the pond using Ansys as a software. The purpose of this study was to compare the results obtained from the pond with other forms of Solar harvesting namely flat plate collectors and panels. The study also revolved around the comparison of salt concentrations at different depths of the pond as time passed and the weather conditions in the area changed. This model has an interesting take on solar ponds as this model has not been presented in the past and hence no basis of comparison unless carried out under different circumstances.[11]

One of the best examples of a solar pond is the one in Catalonia. There is a circular 50 m^2 pond. The depth of the pond is 3m and the salt used is NaCl. The density profile of the pond along the depth is varied between 1.12g/cm^3 to just over 1.2g/cm^3. The salt concentration was roughly 25% by weight while filling the pond up which was done with a help of a diffuser. It is one of the more effective ways of creating salinity gradient associated with solar ponds. One important feature presented in this article was the use of the Froude number to determine inlet flow velocity which is useful to take into consideration when designing solar ponds at any site around the world. Froude number is defined as the ratio of the flow inertia to the external environment field. The pond recorded a peak temperature difference of about 16°C based on monthly averages. The entire list of sensors used to measure other parameters are summarized in the article. The study mentions the equipment used but does not mention how the data was analysed and where it was transmitted to. The other major takeback from the study was the identification of the variability associated with the conditions prevalent to the UCZ[12].

Solar pond systems can be compared to other renewable energy collection systems which may or may not involve solar energy. Each system usually has its own unique characteristics but may require the measurement of similar physical quantities which might need to be transmitted and analysed away from the source.

One such system which uses data transmission, and analysis has been studied, uses the server client mechanism over a TCP/IP protocol. This study is a generic investigation for renewable energy sources, used for energy generation, and is commendable as the results from the sensors for the renewable energy can be shown on the client computer in a user-friendly format using a Java applet. The software for the system which maintains the readings is also written in Java. This paper however does not get into the specifics of how accurate the readings are or the plethora of applications it can be applied but merely mentions it[13].

3. Solar ponds site selection and infrastructure considerations

Solar pond placements, in the best locations selected as per the solar activities around the year, are usually in the rural areas with poor access to the infrastructure. This is the case with Leitchville site, in regional Victoria, near the NSW border. There is no main power infrastructure and no wired telecommunications. Regardless of that, wireless communication coverage is getting better each year. The area has 4G coverage with the speed of 2Mbps up to 75Mbps. Having in mind the communication channel requirements for the transfer of all solar pond data, as already presented and including live video of the pond, site and environment, we can see that nowadays communication infrastructure is not an issue in a new solar pond site selection. In the Leitchville site area Telstra 4GX brings up to two times faster speed compared to regular 4G. It is based on Telstra's 700MHz spectrum and delivers higher data transmission speeds. Even the 4G was more that capable of fulfilling our communication requirements for solar ponds monitoring and control which were presented in the paragraph 1 of this paper, i.e. around 24 Mbytes of data for the whole year. Other service providers also cover the same areas so that telecommunications infrastructure is not a limiting point at the selected location.

Following all of this, a conceptual design of comprehensive communication network, that could support remote monitoring and control of the solar ponds, around the country, is given in Fig. 2.

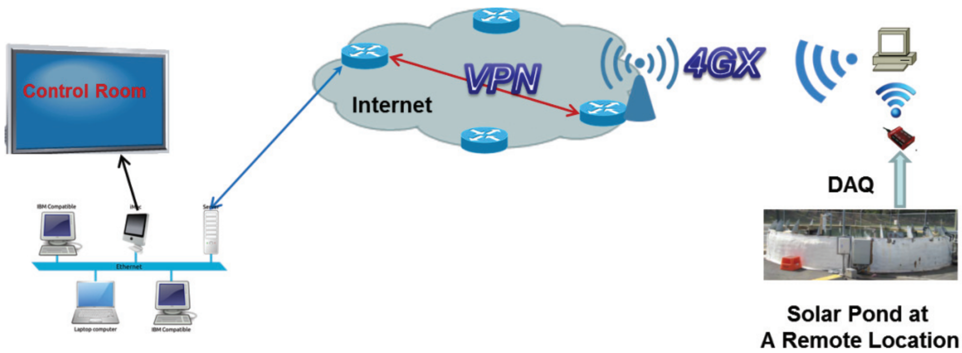

Fig. 2. Remote solar pond monitoring and control system across the country

In the process of data acquisition, we can use data collection concentrators, of different types, like wireless, or wired National Instruments, wired Thermo Fisher dataTakers, or other, connected locally to a PC. We could also use the latest technology like The Internet of Things with imbedded communication capabilities. From the PC or a PC in the local area network (LAN) at the pond site, using terrestrial wireless communication as shown in the Fig. 3, we have access to the Internet. Finally, through the Internet we are using Virtual Private Network (VPN) for the security reasons.

4. Conclusion

In this paper, we have covered the basic working mechanism of solar ponds, as well as, presented some of the sites around the world where they are being operated. We have also explained data monitoring and control systems used on these sites. Finally, we have analyzed solar and infrastructure requirements for the new solar ponds' site. Data collected using DAQ with various sensors, is packaged in the appropriate data structure, presented here. It can than easily be stored locally and transfer to remote monitoring and control centre via secured Internet connection, i.e. VPN. We have presented communication systems' availabilities and the requirements. At this stage of data communications and data storage infrastructure and facilities, there are no restrictions on solar pond and control systems placement anywhere in the country. Power infrastructure, which could be missing, is not an issue since we deal with the green power production plants.

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